Purpose

- AFTA-WFIRST Science Definition Team report (April 2013) identified high level objectives for AFTA-WFIRST DRM and a set of requirements for each science program.
  - Original SDT charter asked what science can you do with the 2.4m telescope responsive to the science priorities for WFIRST.
- HQ has agreed that the science is compelling and we should continue pre-formulation activities for a wide field infrared survey telescope mission using the 2.4m telescope
- As we continue defining this mission, we need to start at the highest level and define what are the key Science Questions, Objectives and Requirements that will drive AFTA-WFIRST .
- Goal over the next ~ 18 months is to develop a consistent and validated set of requirements, starting at Level 1 and flowing down to Survey, Data Set and key Mission design and ops requirements (i.e. requirements for Spacecraft, Telescope, Instrument, and Ground System elements)

Requirements Definition Process

- NWNH Decadal Survey
  - ➢ AFTA-WFIRST Science Definition Team Report
  - ➢ AFTA SDT Charter

Simulations ↑ ↓ Requirements Flow

- Science Questions
- Science Objectives
- Science Requirements

NASA HQ Controlled

Level 1 Program Requirements*

* Science Requirements for Baseline and Threshold Missions, typically set at the end of Phase A.

Iterate as needed to achieve closure

Cosmological Sims

- Sky Survey Rqts

Image Processing Sims

- Mission Data Set Rqts

Design/Operational Sims

Sky Truth

- Observatory Design/Ops Concept

Project Controlled

Level 2 Project Science and Mission Requirements*

* Key programmatic constraints (e.g. mission life, launch vehicle, budget, schedule, etc., as appropriate) must be provided

Defining Level 1 Requirements

- Level 1 (Program) Requirements (NASA HQ Controlled):
  - Science Questions: High-level broad-scope science questions that motivate the AFTA-WFIRST mission
  - Science Objectives: A set of more narrowly focused science objectives motivated by one or more of the Science Questions
  - Science Requirements: Quantifiable requirements tied to one or more of the science objectives that define what the mission must accomplish. Once baselined, they are very difficult to change!
  - The requirements are the tool for defining the mission.
- We want to define the draft Level 1 requirements which then drive the flowdown of all requirements. An example, developed by the Project Office, is shown in the back but we need the SDT's guidance to develop these.
  - These will be draft requirements and we will be iterating these throughout the process.
  - There are multiple ways to do these, e.g. science survey based vs. hardware capability based, so we'll need to select a path (will want to confirm with HQ that they are on board with our approach)
- Would like to review/iterate with chairs and a few SDT members before bringing to the full SDT.

Baseline and Threshold Level 1's

- Two sets of requirements are included in the Level 1 requirements, baseline and threshold
  - Definitions per NASA doc NPR 7120.05E
  - Baseline: The mission performance requirements necessary to achieve the full science objectives of the mission.
  - Threshold: The mission performance requirements necessary to achieve the minimum science acceptable for the investment. In some AOs used for competed missions, threshold science requirements may be called the "science floor" for the mission.
    - If predicted performance falls below the threshold requirement during development, a termination review is required.
- Initially, we want to focus on the draft baseline requirements, but we will eventually want to discuss what reasonable draft threshold requirements should be.

Defining Level 2 Requirements

- Science and Mission Requirements
  - Sky Survey Requirements: Specification of new sky object/event information needed to meet Level 1 Science Rqts
    - Cosmological simulations trade-off and optimize the Survey requirements to assure that Level 1 requirements can be met (with margin) by analyzing the new sky object/event information;
  - Mission Data Set Requirements: Definition of images, calibration data, pointing histories, etc. sufficient to allow sky object/event extraction
    - Image Processing simulations trade-off and optimize the mission data set requirements to assure that the required sky object/event information can be extracted from the specified data sets;
  - Observatory Design and Operations Concept: Definition of Observatory design details at the S/C, Telescope, and Instrument level suitable for assessing the ability of the Mission to deliver the required data sets within the time allocated for the orbit selected
    - Detailed Mission Simulations (e.g. STOP analyses of all observing modes) trade-off and optimize observatory design and ops concepts to assure that the required mission data sets can be delivered within the time available.
  - Iterate any of the simulations as needed to achieve design closure

Simulations

- Simulations are key for setting the detailed requirements.
  - We need to start working on these in parallel with the requirements development activity … they are critical to requirements traceability
- Do we already have the capability/resources to perform each of the identified simulations or are new simulation capabilities/resources required?
  - Would like to identify key simulations that are required, determine if the capability currently exists or needs to be developed, and identify a plan to develop, if required.
  - "Sky Truth" input assumptions will be key to the Mission Simulations overviewed at the bottom of the previous page. Depending on how the Level 1 requirements are written, some "Sky Truth" reference assumptions (e.g. Hα Luminosity Function) might need to be agreed to at Level 1 to support a solid Level 2 flowdown, but the goal is to avoid this (see p.8 comment on rqts vs predictions).
- These simulations take a while to set up, but we can still define the requirement flowdown structure with placeholder requirement values which can be validated when the simulations are available.

WFIRST-2.4 Science Objectives:

1) Produce a deep map of the sky at NIR wavelengths.
2) Determine the expansion history of the Universe and the growth history of its largest structures in order to test possible explanations of its apparent accelerating expansion including Dark Energy and modifications to Einstein's gravity.
3) Provide a guest observer program utilizing a minimum of 25% of the mission minimum lifetime
4) Complete the statistical census of planetary systems in the Galaxy, from the outer habitable zone to free floating planets, including analogs of all of the planets in our Solar System with the mass of Mars or greater.
5) Directly image giant planets and debris disks from habitable zones to beyond the ice lines, around nearby AFGK stars, at visible wavelengths, and characterize their physical properties by measuring brightness, color, spectra, and polarization while providing information to constrain their orbital elements with an optional coronagraph.

WFIRST-2.4 Survey Capability Rqts

NIR High Latitude Surveys

High Latitude Spectroscopic Survey

- $\geq$1070 deg^2 per dedicated observing year (combined HLS imaging and spectroscopy)
- A comoving density of galaxy redshifts n>6x10^{-4} Mpc^{-3} at z=1.9 according to Colbert + LF.
- Redshift range $1.10 \leq z \leq 1.95$ for Hα
- Redshift errors $\sigma_z \leq 0.001(1+z)$, equivalent to 300 km/s rms
- Misidentified lines $\leq$5% per source type, $\leq$10% overall; contamination fractions known to 2×10^{-3}

High Latitude Imaging Survey

- $\geq$ 1070 deg^2 per dedicated observing year (combined HLS imaging and spectroscopy)
- Ability to measure a galaxy density of $\geq$60/amin^2, shapes resolved plus photo-z's
- Additive shear error $\leq 3\times10^{-4}$
- Multiplicative shear error = 0.2% per redshift slice (17 slices)
- Photo-z error distribution width $\leq 0.04(1+z)$, catastrophic error rate <2%
- Systematic error in photo-z offsets $\leq 0.002(1+z)$

Supernova SN-Ia Survey

- >100 SNe-Ia per Δz=0.1 bin for all bins for 0.4 < z < 1.7, per dedicated 6 months
- Observational noise contribution to distance modulus error $\sigma_\mu \leq 0.02$ per Δz=0.1 bin up to z = 1.7
- Redshift error $\sigma \leq 0.005$ per supernova
- Relative instrumental bias $\leq$0.005 on photometric calibration across the wavelength range

Exoplanet Surveys

Microlensing Survey

- Planet detection capability to ~0.1 Earth masses ($M_\oplus$)
- Ability to detect $\geq$ 1500 bound cold planets in the mass range of 0.1-10,000 Earth masses, including 150 planets with mass <3 Earth masses
- Ability to detect $\geq$ 20 free floating Earth-mass planets

Optional Coronagraphy Survey

- Field of view from 0.1 – 1.5 arcsec at 400 nm, scaling linearly with wavelength up to 1000 nm (inner and outer radii of detection and characterization region)
- Allow for a survey of at least 150 stars with non-zero probability of detection
- Ability to image disks and map their structure with sub-AU angular resolution
- Single detection/characterization waveband of at least 10%

WFIRST-2.4 Data Set Rqts

NIR High Latitude Surveys Data Sets

High Latitude Spectroscopic Survey Data Set Rqts

- Slitless grism, spectrometer, ramped resolution 550-800 over bandpass
- S/N $\geq$7 for r_{eff} = 300 mas for Hα emission line flux at 1.8 μm $\geq 1.0\times10^{-16}$ erg/cm^2-s
- Bandpass $1.35 \leq \lambda \leq 1.95$ μm
- Pixel scale $\leq$ 110 mas
- System PSF EE50% radius 240 mas (1.35 μm), 180 mas (1.65 μm), 260 mas (1.95 μm)
- $\geq$3 dispersion directions required, two nearly opposed
- Reach J_{AB}=24.0 AND (H_{AB}=23.5 OR F184$_{AB}$=23.1) for r_{eff}=0.3 arcsec source at 10 sigma to achieve a zero order detection in 2 filters

High Latitude Imaging Survey Data Set Rqts

- From Space: 3 shape/color filter bands (J,H,F184) and 1 color filter band (Y; for photo-z)
- S/N $\geq$18 (matched filter detection significance) per shape/color filter for galaxy r_{eff} = 180 mas and mag AB = 24.7/24.6/24.1 (J/H/F184)
- PSF second moment ($I_{xx} + I_{yy}$) known to a relative error of $\leq 9.3\times10^{-4}$ rms (shape/color filters only)
- PSF ellipticity (I_{xx}-I_{yy}, 2*I_{xy})/ ($I_{xx} + I_{yy}$) known to $\leq 4.7\times10^{-4}$ rms (shape/color filters only)
- System PSF EE50 radius $\leq$0.12 (Y band), 0.12 (J), 0.14 (H), or 0.13 (F184) arcsec
- At least 5 (H,F184) or 6 (J) random dithers required for shape/color bands, and 5 for Y at same dither exposure time
- From Ground: 5 filters spanning at least 0.35-0.92 μm
- From Ground + Space combined: Complete an unbiased spectroscopic PZCS training data set containing $\geq$ 100,000 galaxies $\leq$ mag AB = 24.6 (in JHF184 bands) and covering at least 4 uncorrelated fields; redshift accuracy required is σ_z<0.01(1+z)

Supernova Survey Data Set Rqts

- Minimum monitoring time-span for an individual field: ~2 years with a sampling cadence $\leq$5 days
- Cross filter color calibration $\leq$0.005
- Three filters, approximately Y, J, H for SN discovery
- IFU spectrometer, $\lambda/\Delta\lambda$ ~100, 2-pixel (S/N $\geq$ 10 per pixel bin) for redshift/typing
- IFU S/N $\geq$15 per synthetic fiber band for points near lightcurve maximum in each band at each redshift
- Dither with 30 mas accuracy
- Low Galactic extinction, E(B-V) $\leq$0.02

Exoplanet Surveys Data Sets

Microlensing Survey Data Set Rqts

- Monitor ~3 square degrees in the Galactic Bulge for at least 250 total days
- S/N $\geq$100 per exposure for a J=20.5 star
- Sample light curves with wide filter W149 with λ =0.927-2.0 μm
- Photometric sampling cadence in W149 of $\leq$15 minutes
- $\leq$0.4" angular resolution to resolve the brightest main sequence stars
- Monitor microlensing events continuously with a duty cycle of $\geq$80% for at least 60 days
- Monitor fields with Z087 filter, 1 exposure every 12 hours
- Separation of >2 years between first and last observing seasons

Optional Coronagraphy Survey Data Set Rqts

- Detection limit after PSF calibration of 1 part per billion or better over entire field of view and wavelength band
- Spectral resolution of at least 70 from 400 to 1000 nm
- Multi-band polarimetric imaging with 5% accuracy and 2% precisions per spatial resolution element for disk characterization (grain size distribution, disk geometry) and identification of large polarimetric features in gas giants
- Critically sampled PSF at shortest wavelength

Partial Rqts Flowdown from AFTA-WFIRST SDT Report (April 2013) … Observatory Design/Ops Concept on Separate Page, not shown

This flowdown jumps straight from Science Objectives to detailed Level 2 requirements.

Proposed Process

- Work with a small group of SDT members on draft Level 1's
  - Goal is to complete by mid October
- Once we have consensus on the initial draft Level 1's, work with science leads on the flowdown to Level 2 sky survey, data set, and observatory design/ops requirements, including key telescope, instrument, and spacecraft requirements
  - The first step would be to assess the existing requirements identified in the report
    - Ensure that we have captured all of the key Level 2 requirements
    - Ensure that what we have captured are requirements and not predictions
  - This is probably best worked in small groups with periodic reporting to the full SDT
- As updates/additions are made, we begin the process of validating/ iterating the requirements through the simulation process
  - This is an iterative process where both the draft Level 1 and draft Level 2 requirements will be updated.
  - Goal is to be able to validate each requirement with a simulation or at least identify the simulation to be performed if a sim not available at the time.

Examples of Draft Questions, Objectives, & Level 1 Requirements

Draft AFTA-WFIRST Questions

1) Is cosmic acceleration caused by a new energy component or by the breakdown of General Relativity (GR) on cosmological scales? (*SDT report 2.2*)
2) If the cause is a new energy component, is its energy density constant in space and time, or has it evolved over the history of the universe? (*SDT report 2.2*)
3) How do planetary systems form and evolve? (*SDT report, end of 2.5.1.3*)
4) What kinds of unexpected systems inhabit the cold, outer regions of planetary systems? (*SDT report, end of 2.5.1.3*)
5) What is the amount and location about the star of circumstellar dust? (*SDT report, end of 2.5.2.3*)
6) What large-scale structures are present in disks? (*SDT report, end of 2.5.2.3*)
7) What are the sizes and compositions of the debris dust grains? (*SDT report, end of 2.5.2.3*)

Options for Other Science Questions Addressed by DE Surveys

1) What is the history of Galaxy formation in the first billion years after the Big Bang?
2) What is the distribution of dark matter on intermediate and large scales?
3) What is the structure of dark matter in the Galaxy, and how was its merger history?
4) What is the origin of the correlation of central black hole mass with galaxy mass and with star formation?

Note: These come from section 2.3 of the SDT Report

AFTA-WFIRST Objectives (from SDT report)

- Determine the expansion history of the Universe and the growth history of its largest structures in order to test possible explanations of its apparent accelerating expansion including Dark Energy and modifications to Einstein's gravity.
- Produce a deep map of the sky at NIR wavelengths.
- Complete the statistical census of planetary systems in the Galaxy, from the outer habitable zone to free floating planets, including analogs of all of the planets in our Solar System with the mass of Mars or greater.
- Provide a guest observer program ~~utilizing a minimum of 25% of the mission minimum lifetime~~.
- Directly image giant planets and debris disks from habitable zones to beyond the ice lines, around nearby AFGK stars, at visible wavelengths, and characterize their physical properties by measuring brightness, color, spectra, and polarization while providing information to constrain their orbital elements with a~~n optional~~ coronagraph.

Survey and Hardware Based Requirements of AFTA-WFIRST

<u>Science Survey Based</u>

- <u>High Latitude Imaging Survey</u>:
  - Survey area: 2000 deg^2
  - Duration: 1.3 years
  - Bandpass: Four filters (Y,J,H,F184), spanning 0.92μm to 2.0μm
  - Depth: 5σ point-source sensitivity AB=26.7 [could replace this and the survey area requirements with a spec on the number of galaxy shape measurements made in a given redshift range]
  - Image quality: suitable for weak lensing shear measurement in J,H,F184.
  - Photometric accuracy: Imaging data to be compatible with a radiometric calibration having an absolute uncertainty no greater than 2 percent (rms) for galaxies with FWHM=0.3 arcsec and J(AB)<25 [could replace with σ_z spec on photo-z determination, but verification will require reference to LSST capabilities.]
- <u>High Latitude Spectroscopic Survey</u>:
  - Survey area: 2000 deg^2
  - Duration: 0.6 years
  - Bandpass: 1.35μm to 1.95μm
  - Depth (point source minimum detected line flux @ 1.65 μm): 0.5×10^{-16} ergs/cm^2/s at 7σ [could replace this and the survey area requirements with spec on number of galaxy redshifts to measure in a given redshift range]
  - Point-source spectral resolution: 550-800
  - Wavelength accuracy: sufficient to achieve $\sigma_z < 0.001*(1+z)$ in calibrated spectra
- <u>SNIa survey</u>:
  - Imaging Wide: 27 deg^2 at 5σ depths Y(AB)=27, J(AB)=27.5.
  - Imaging Medium: 9 deg^2 at 5σ depths J(AB)=27.6, H(AB)=28.1.
  - Imaging Deep: 5 deg^2 at 5σ depths J(AB)=29.3, H(AB)=29.4.
  - Spectroscopy Depth: 7 exposures with S/N=3/pix, 1 exp near lightcurve peak with S/N=10/pix, 1 exp post-SN reference with S/N=6/pix
  - Spectroscopy equivalent point-source resolution: 50<R<100.
  - Wavelength accuracy: sufficient to achieve $\sigma_z < 0.005*(1+z)$ in calibrated spectra
  - Spectroscopy field of view and sampling: sufficient for host-galaxy subtraction
  - Spectrophotometric accuracy: Capability to produce calibrated spectra of point sources with relative uncertainty of less than 1% per octave in wavelength.
- <u>Exoplanet Microlensing</u>:
  - Survey area: 2.8 deg^2
  - Cadence: 15 minutes for W filter, 12 hours for Z filter
  - Bandpass: two filters – Z(0.76 μm - 0.977 μm) and W(0.927 μm – 2.0 μm)
  - Duration: 6 seasons widely separated in mission, each season being 72 continuous days.
  - Dynamic range: Imaging data to be compatible with a radiometric calibration having a relative uncertainty no greater than 1 percent (rms) for stars with 16<J(AB)<20.
- <u>Coronagraph</u>:
  - <u>Broad band imaging</u>: 0.40μm to 1.0μm, bandpass of individual filters to be no less than 10% (Specify individual filters?)
  - <u>Integral Field Spectrograph (IFS)</u>: 0.40μm to 1.0μm
  - The inner working angle will be no greater than 3λ/D (ref: at 500nm and D=2.4m, this corresponds to 130mas)
  - The outer working angle will be no less than 15λ/D.
  - IFS: equivalent point-source resolution 50<R<100 (TBC).
  - Able to detect gas-giant planets and bright debris disks at 1ppb brightness relative to host star.
  - [Not sure what to say about duration and/or number of stars to observe – do we have enough information on known targets and likely observing time per star? Just put placeholders for now?]

<u>Hardware Based</u>

- Broad band imaging: 0.76μm to 2.0μm
- Slitless spectroscopy: 1.35μm to 1.95μm
- SNIa spectroscopy (IFS): 0.60μm to 2.0μm
- Slitless spectroscopy: equivalent point source resolution 550<R<900.
- SNIa spectroscopy (IFS): equivalent point-source resolution 50<R<100.
- The sensitivity will be sufficient to achieve a minimum signal to noise of 5 in each imaging filter for point sources of brightness AB=26 and for a galaxy with an exponential disk profile with half-light radius=0.3" and brightness AB=25. [Alternative is just to specify throughput and detailed requirements on instrumental noise contributions, but this gets unwieldy and makes it more difficult to trade S/N budget items against one another later. I have deliberately left out a spec on exposure time, but that bears some discussion.]
- The sensitivity will be sufficient to achieve a minimum detectable line flux of 0.5×10-16 ergs/cm2/s at 7σ significance at 1.65 μm for a point source.
- Imager: Instrumented focal plane area greater than 0.25 (TBC) square degrees, as projected onto the sky.
- SNIa IFS: greater than 2.5" x 2.5"
- Imager slitless spectroscopy: calibrated spectral data must support a redshift measurement accuracy $\sigma_z < 0.001*(1+z)$
- IFS: calibrated spectral data must support a redshift measurement accuracy $\sigma_z < 0.005*(1+z)$
- Imaging data to be compatible with a radiometric calibration having a relative uncertainty no greater than 1 percent (rms) for stars with 16<J(AB)<20 [TBC – driven by microlensing]
- Imaging data to be compatible with a radiometric calibration having an absolute uncertainty no greater than 2 percent (rms) for galaxies with FWHM=0.3 arcsec and J(AB)<25 [TBC – driven by weak lensing photo-z]
- Imager: Spectral data to be compatible with a relative calibration uncertainty no greater than 15 percent (rms)
- IFS: Spectra with high photometric accuracy to be obtained for point sources with a continuum flux as bright as V=17 (for calibration with DA white dwarfs standardized by HST)
- IFS: Capability to produce calibrated spectra of point sources with relative uncertainty of less than 1% per octave in wavelength
- Capability to observe all stars except the Sun without risk of detector damage.

- Broad band imaging: 0.40μm to 1.0μm (Specify individual filters?)
- IFS: 0.40μm to 1.0μm
- A post-processing contrast ratio of 10-8 (or 10-9?) is to be achieved over a 10% bandpass;
- The inner working angle at which this contrast is to be achieved will be no greater than 3λ/D (ref: at 500nm and D=2.4m, this corresponds to 130mas)
- The outer working angle at which this contrast is to be achieved will be no less than 15λ/D.
- IFS: equivalent point-source resolution 50<R<100 (TBC).
- (Specify throughput, or specify S/N at given AB for a point source in a given period of time?)

These are too detailed for Level 1, but they describe the mission defined in the AFTA-WFIRST SDT report.
Note: There are no explicit performance requirements included that depend on potential astrophysical uncertainties or systematics. For example: there are no requirements on the uncertainties in cosmological parameters to be derived from AFTA-WFIRST datasets.

Example Draft Level 1 Science Rqmts

- Dark Energy
  - Measure the spectra of galaxies at a rate of TBD/yr with spectral resolutions of approximately TBD over TBD μm wavelength range and to an emission line flux limit of TBD to provide measurements of the Hubble parameter H(z) and angular diameter distance Da(z) via Baryon Acoustic Oscillations (BAO).
  - Measure the shapes of galaxies at a rate of TBD/yr using multi-band imaging over TBD μm wavelength range to characterize the growth of structure in the universe via weak lensing.
  - Measure the light curve shape and spectra of SNIa with spectral resolutions of approximately TBD over TBD μm wavelength range to measure the luminosity distance of type Ia supernovae to characterize the expansion history of the universe.
- Exoplanets
  - Measure the light curve shapes generated by microlensing of background stars by planets over TBD wavelength range to a TBD sensitivity to determine the mass function of cold exoplanets for planet separations from the outer habitable zone extending to unbound planets.
  - Using direct multi-band imaging and spectroscopy, characterize giant exoplanets, including both newly-discovered planets and known planets discovered by radial-velocity techniques for a sample of TBD nearby stars within 10 pc of the Sun over TBD μm wavelength range.
  - Characterize the large scale structure of debris disks, and the size and composition of the dust grains in these disks, at radii corresponding to the habitable zone and larger, for a sample of TBD nearby stars within 100 pc of the Sun over TBD μm wavelength range.
- Guest Investigator/Observer
  - The observatory shall enable a wide range of survey science by providing broad-band filters spanning 0.76-2.0 μm (TBR) and slitless spectroscopy, with a system PSF that is diffraction limited at 1.2 μm and above.
  - At least 25% (TBR) of the observing program shall be set aside for a guest observer program.

Level 1 Examples from Recent Missions

JWST Level 1 Requirements – circa 2008

- **Baseline Science Requirements**
  - L1-1 Measure the space density of galaxies to a 2 micrometer flux density limit of 1.0×10^{-34} $Wm^{-2}Hz^{-1}$ via imagery within the 0.6 to 27 micrometers spectral band to enable the determination of how this density varies as a function of their age and evolutionary state.
  - L1-2 Measure the spectra of at least 2500 galaxies with spectral resolutions of approximately 100 (over 0.6 to 5 micrometers) and 1000 (over 1 to 5 micrometers) and to a 2 micrometer emission line flux limit of 5.2×10^{-22} Wm^{-2} to enable determination of their redshift, metallicity, star formation rate, and ionization state of the intergalactic medium.
  - L1-3 Measure the physical and chemical properties of young stellar objects, circumstellar debris disks, extra-solar giant planets, and Solar System objects via spectroscopy, and imagery within the 0.6 to 27 micrometers spectral band to enable further determination of how planetary systems form and evolve.
  - L1-4 Enable, within a 5-year mission, a total observing time of at least 1.1×10^{8} seconds on targets located at any position on the celestial sphere.
- **Threshold Science Requirements**
  - L1-5 Measure the space density of galaxies to a 2 micrometer flux density limit of 1.0×10^{-34} $Wm^{-2}Hz^{-1}$ via imagery within the *1.7 to 10* micrometers spectral band to enable the determination of how this density varies as a function of their age and evolutionary state.
  - L1-6 Measure the spectra of at least *1000* galaxies with spectral resolutions of approximately 100 (over *1.7* to 5 micrometers) and 1000 (over *1.7* to 5 micrometers) and to a 2 micrometer emission line flux limit of 5.2×10^{-22} Wm^{-2} to enable determination of their redshift, metallicity, star formation rate, and ionization state of the intergalactic medium.
  - L1-7 Measure the physical and chemical properties of young stellar objects, circumstellar debris disks, extra-solar giant planets, and Solar System objects via spectroscopy, and imagery within the *1.7 to 10* micrometers spectral band to enable further determination of how planetary systems form and evolve.
  - L1-8 Enable a total observing time of at least *5.5×10^{7}* seconds on targets located at any position on the celestial sphere.
- **Mission and Spacecraft Performance Requirements**
  - L1-9 The JWST Spacecraft, telescope and instruments shall be designed for at least a 5-year lifetime. Level 1 performance shall be achieved for a minimum of 5 years.
  - L1-10 The operational JWST system shall deliver to the Science and Operations Center (S&OC) a minimum of 95 percent of all real-time telemetry and stored data.
  - L1-11 The JWST Project shall plan for a launch date as early as June 2013.
  - L1-12 The JWST shall orbit the Sun-Earth second Lagrange point (L2 point).
  - L1-13 The JWST Optical Telescope Element (OTE) shall have a primary mirror whose unobscured light collecting area is no less than 25 square meters.
  - L1-14 The Observatory, over the field of view (FOV) of the Near-Infrared Camera (NIRCam) shall be diffraction limited at 2 micrometers defined as having a Strehl Ratio greater than or equal to 0.8.

GLAST (Fermi) Level 1 Requirements

Large Area Telescope Requirements

- The sensitivity for a 5 sigma detection of a high latitude gamma ray source after 1 year of scanning shall be:
  - Requirement: <6 x 10^{-9} photons cm^{-2} s^{-1}.
  - Minimum: <8 x 10^{-9} photons cm^{-2} s^{-1}.
- The source location determination for a high latitude gamma ray source, with 10^{-7} cm^{-2} s^{-1} flux at >100 MeV and with a photon spectral index of -2.0 above a flat background and assuming no spectral cut-off to 10 GeV, after 1-year of survey shall be:
  - Requirement: <0.5 arcminutes, 1 sigma radius
  - Minimum: <1 arcminutes, 1 sigma radius
- The peak effective area for the gamma ray detection in the 1 – 10 GeV band, on-axis, shall be:
  - Requirement: >8000 cm^2
  - Minimum: >8000 cm^2
- The energy range over which the gamma ray flux measurements can be made shall be:
  - Requirement: < 20 MeV to > 300 GeV
  - Minimum: < 30 MeV to > 100 GeV
- The background rejection of high latitude diffuse background, in any decade of energy for E > 100 MeV (assuming a high latitude diffuse flux of 1.5 x 10^{-5} cm^{-2} s^{-1} sr^{-1}, a photon spectral index of –2.1, and no spectral break), shall be:
  - Requirement: <10%
  - Minimum: <15%
- The energy resolution of the gamma ray measurements shall be (1 sigma, on-axis, 100 MeV – 10 GeV):
  - Requirement: <10%
  - Minimum: <20%
- The field of view of the gamma ray telescope shall be
  - Requirement: >2 sr
  - Minimum: >1.5 sr

GLAST Burst Monitor Instrument

- As a goal, the GLAST mission shall be capable of detecting gamma ray bursts, with the following GBM performance capabilities:
- The burst measurement capability shall have a peak brightness GRB sensitivity for a 5 sigma detection in the 50-300 keV range of less than 1.0 photons cm^{-2} $s.^{-1}$
- The burst measurement capability shall have an energy range between 20 keV and 20 MeV
- The burst measurement capability shall have an energy resolution between 0.1 and 1.0 MeV of less than 12%, 1 sigma, on axis.
- The burst measurement capability shall determine the GRB real time location for a burst of brightness 10 photons cm^{-2} s^{-1} in the 50-300 keV band and a duration of 1 second or longer. (No minimum location accuracy is required.)

Kepler Level 1 Requirements

- **Baseline Science Rqmts-Flight**
  - Have a mission lifetime of at least 3.5 years after commissioning.
  - Continuously and simultaneously monitor at least 100,000 F,G,K, and M dwarf stars that range from visual magnitude 9 to 15.
  - Develop and operate a photometer with sufficient photometric precision to enable the detection of signal amplitudes expected from Earth-size planetary transits of solar-like stars. In particular, the 1 sigma total noise must be < 20 parts per million (including 10 ppm of stellar variability noise) for an integration of 6.5 hours on a G2 dwarf with $m_v = 12$.
- **Baseline Science Rqmts-Ground**
  - Analyze the scientific data associated with each target star for evidence of transits by Earth-size or larger planets.
- **Baseline Science Rqmts-Ground+Follow Up**
  - Maximize the reliability of each discovery by minimizing false positive events. Produce a statistically meaningful result by minimizing the number of false-positives events and quantifying the result by estimating the probability of remaining false positives. Use Kepler photometric data and ground-based observations to rule out statistical fluctuations, transits from eclipsing binaries, and other confounding sources. Compute the reliability of each discovery by determining the expected number of eclipsing background binaries of similar period in the confusion aperture surrounding the target star.
- **Baseline Science Rqmts-Follow-Up**
  - Determine the characteristics of the discovered planetary systems containing Earth-size planets by means of follow-up observations using complementary techniques.
  - After discovering a transiting planet, search for other planets in the same planetary system using ground based-radial velocity observations.
  - Associate planetary characteristics with those of the parent star by means of ground-based follow-up observations.

- **Threshold Science Rqmts-Flight**
  - Have a mission lifetime of at least *3* years after commissioning.
  - Continuously and simultaneously monitor at least *10,000 dwarf stars* that range from visual magnitude 9 to 15.
  - Develop a photometer with sufficient photometric precision to enable the detection of amplitudes expected from transits of planets *of no more than 1.3 times the radius of the Earth* orbiting solar-like stars. In particular, the total noise must be *< 40 ppm* (including 10 ppm of stellar variability noise) for an integration of 6.5 hours on a G2 dwarf with $m_v = 12$.
- **Threshold Science Rqmts-Ground**
  - Analyze the scientific data associated with each target star for evidence of transits by Earth-size or larger planets.
- **Threshold Science Rqmts-Ground+Follow Up**
  - Maximize the reliability of each discovery by minimizing false positive events. Produce a statistically meaningful result by minimizing the number of false-positives events and quantifying the result by estimating the probability of remaining false positives. Use Kepler photometric data and ground-based observations to rule out statistical fluctuations, transits from eclipsing binaries, and other confounding sources. Compute the reliability of each discovery by determining the expected number of eclipsing background binaries of similar period in the confusion aperture surrounding the target star.
- **Threshold Science Rqmts-Follow-Up**
  - Determine the characteristics of the discovered planetary systems containing Earth-size planets by searching for other planets in the systems using complementary techniques such as radial-velocity which will provide both the masses and orbital parameters of these additional planets.
  - Associate planetary characteristics with those of the parent star by means of ground-based follow-up observations.

Kepler continued

- Mission Requirements
  - The Kepler Mission shall operate in an Earth-trailing heliocentric orbit that will allow it to meet the continuous viewing requirement while remaining close enough to Earth to provide a high-rate communications link. This orbit also minimizes the orbit perturbations and environmental effects on the Photometer associated with a low-Earth orbit.
  - A minimum of three transits with sufficient statistical significance (i.e., SNR>7) and indicating a consistent period, duration, and depth shall define reliable planet detection. Following a one month on-orbit commissioning period, the Kepler spacecraft shall acquire the selected field-of-view and begin a 3.5 year study of the star field. The Science Team shall analyze the data to detect the periodic decrease in the stellar brighness due to planetary transits. Transits by terrestrial-size planets produce a fractional change in stellar brightness of about 80 ppm and are expected to last several hours. The orbit and size of the planet can be calculated from the period, depth of transit, and the mass and size of the star. The latter two quantities are determined from the ground-based stellar classification program and the follow-up observing program.
  - The spacecraft shall provide to ground teams real time engineering telemetry on the health and performance of the spacecraft during certain spacecraft activities such as the quarterly roll maneuver.
- Instrument Requirements
  - The photometer shall meet the science performance requirements after launch and during mission operations.
  - The photometer shall be a Schmidt Camera-design optical system with at least a 100 square degrees active field-of-view.
  - During operations, the Photometer shall observe a single star field and simultaneously monitor more than 100,000 dwarf stars for 3.5 years.
  - The photometer shall reliably detect transits of Earth-size planets in one-year orbits around solar-like stars of apparent visual magnitude 12 (m_v = 12) by means of differential photometric techniques.
  - The photometric response range of the photometer shall include stars with apparent magnitude greater than or equal to m_v = 9 and less than or equal to m_v = 15 in the active FOV.

SIRTF/Spitzer Level 1 Requirements

- **Baseline Science Rqmts**
- **Threshold Science Rqmts**